

DEVELOPING UNIT USING A DEVELOPING LIQUID AND  
IMAGE FORMING APPARATUS INCLUDING THE SAME

BACKGROUND OF THE INVENTION

The present invention relates to a developing unit of the type developing a latent image formed on an image carrier by depositing a developing liquid, which consists  
— of a carrier liquid and a developing substance, and a copier,  
5 of a carrier liquid and a developing substance, and a copier, facsimile apparatus, printer or similar image forming apparatus including the same.

A developing unit for use in an image forming apparatus uses either one of a dry powdery developer or  
10 a developing liquid. Generally, a developing unit using a developing liquid includes a developing roller rotatable while carrying the liquid thereon. A voltage for development is applied to the developing roller to thereby form an electric field between the roller and an image  
15 carrier.

The problem with a developing unit of the type described is that a toner image formed thereby is sometimes irregular. By a series of researches and experiments, I found that irregular development was ascribable to the  
20 unstable strength of the electric field. Further, I found

that in a so-called contact type developing unit that develops the latent image with the developing roller contacting the image carrier, irregularities on the surface of the roller cause fine irregularities to appear on the surface of the developing liquid deposited on the roller, also making development irregular.

#### SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a developing unit using a developing liquid and capable of reducing irregular development, and an image forming apparatus including the same.

In accordance with the present invention, a developing unit for developing a latent image formed on an image carrier with a developing liquid consisting of a carrier liquid and a developing substance includes a developing roller including a roller portion and configured to rotate while carrying the developing liquid on the roller portion. A voltage applying device applies a voltage to the roller portion to thereby form an electric field for development between the roller portion and the image carrier. The electric field transfers the developing liquid deposited on the roller portion to a latent image formed on the image carrier. The roller portion has a volume resistivity ranging from  $0 \Omega \cdot \text{cm}$  to

10<sup>7</sup> Ω·cm.

Further, in accordance with the present invention, an image forming apparatus includes an image carrier configured to carry a latent image thereon. A developing unit develops the latent image by depositing a developing liquid, which consists of a carrier liquid and a developing substance, on the latent image. A developing roller includes a roller portion and rotates while carrying the developing liquid on the roller portion. A voltage applying device applies a voltage to the roller portion to thereby form an electric field for development between the roller portion and the image carrier. The electric field transfers the developing liquid from the roller portion to the latent image formed on the image carrier. The roller portion has a volume resistivity ranging from 0 Ω·cm to 10<sup>7</sup> Ω·cm.

#### BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features and advantages of the present invention will become more apparent from the following detailed description taken with the accompanying drawings in which:

FIG. 1 is a view showing an image forming apparatus embodying the present invention;

FIG. 2 is a fragmentary section showing a

photoconductive drum and a developing roller included in the illustrative embodiment;

FIG. 3 is a sketch of a solid image achievable when a roller portion forming part of the developing roller has a ten-point mean surface roughness of  $3\text{ }\mu\text{m}$  or less;

FIG. 4 is a sketch of a solid image formed when the roller portion has a ten-point mean surface roughness of  $4\text{ }\mu\text{m}$  or above;

FIG. 5 is a graph showing a relation between a nip pressure and the hardness of the roller portion for a given nip width of the roller portion; and

FIG. 6 is a graph showing a relation between the nip width  $W$  and the hardness (JIS (Japanese Industrial Standards) A scale) of the roller portion for a given nip pressure.

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIG. 1 of the drawings, an image forming apparatus embodying the present invention is shown and implemented as an electrophotographic printer by way of example. As shown, the printer includes a photoconductive drum 1 that is a specific form of an image carrier. A charge roller 2, an exposing unit 3, a developing unit 10, an image transferring device 5 and a cleaning unit 6 are arranged around the drum 1. A paper feeding device 7 and a fixing

unit 9 are respectively located at the right-hand side and left-hand side of the image transferring device, as viewed in FIG. 1.

5 While the drum 1 is rotated counterclockwise, as viewed in FIG. 1, the charge roller 2 uniformly charges the surface of the drum 1. The exposing unit 3 optically scans the charged surface of the drum 1 in accordance with image data to thereby form a latent image thereon. The developing unit 5 develops the latent image with toner,  
10 which is a developing substance contained in a developing liquid 4, for thereby forming a corresponding toner image.

The developing liquid 4 consists of a carrier liquid and toner densely dispersed in the carrier liquid. The carrier liquid may be implemented by dimethyl polysiloxane  
15 oil or similar insulative liquid. The developing liquid 4 has viscosity as high as 100 to 10,000 Pa's.

A paper sheet 8 is fed from the paper feeding device 7 to the image transferring device 5 at a preselected timing. The image transferring device 5 transfers the toner image  
20 from the drum 1 to the paper sheet 8. The paper sheet 8 carrying the toner image thereon is conveyed to the fixing unit 9. The fixing unit 9 fixes the toner image on the paper sheet 8 with heat and pressure. The cleaning unit 9 mechanically scrapes off the developing liquid 4 left  
25 on the drum 1 after the image transfer.

The procedure described above is repeated to form toner images on consecutive paper sheets 8 sequentially fed from the paper feeding device 7.

The developing unit 10 includes a reservoir 11 storing the developing liquid 4. The reservoir 11 accommodates therein a developing roller or developer carrier 12, an applying roller 14, a metering blade 15, a collecting blade 16, a circulation pump 17, and a screw or agitator 18. The metering blade regulates the thickness of the developing liquid 4 applied to the developing roller 12 by the applying roller 14. The collecting blade 16 collects the developing liquid 4 left on the developing roller 12. The circulation pump 17 circulates the developing liquid 4 in the reservoir 11 while the screw 18 agitates the liquid 4.

A partition 19 is positioned at the center of the reservoir 11 and extends in the axial direction of the applying roller 14. The partition 19 causes the developing liquid 4 to be circulated. Specifically, the partition 19 divides the reservoir 11 into a feeding portion 20a for feeding the developing liquid 4 to the applying roller 14 and a collecting portion 20c for collecting the liquid 4 left on the developing roller 12. The feeding portion 20a and collecting portion 20c are communicated to each other via a communicating portion 20,

which is formed below the partition 19. The developing liquid 4 removed from the applying roller 14 is recirculated to the collecting portion 20c via a recirculating portion 20d, which is formed above the partition 19. In this manner, a circulation path is formed between the inner periphery of the reservoir 11 and the partition 19.

The circulation pump 17 is positioned at the boundary between the feeding portion 20a and the communicating portion 20d. The circulation pump 17 is implemented by a gear pump operatively connected to an electric motor not shown. Alternatively, use may be made of the combination of a one-way valve and a piston so long as it can cause the developing liquid 4 to flow along the above-described circulation path. The circulation pump 17 circulates the developing liquid 4 via the feeding portion 20a, recirculating portion 20b, collecting portion 20c and communicating portion 20d in this order.

The applying roller 14 is positioned in the upper part of the feeding portion 20a and rotatable clockwise, as viewed in FIG. 1, for scooping up the developing liquid 4. The metering blade 15 uniforms the thickness of the developing liquid 4 carried on the applying roller 14. The applying roller 14 applies the developing liquid 4 to the developing roller 12.

Drive means, not shown, rotates the screw or agitator 18 clockwise, as viewed in FIG. 1. The screw 18, intervening between the collecting portion 20c and the communicating portion 20d, delivers the developing liquid from the collecting portion 20c to the communicating portion 20d while agitating it.

A hole, not shown, is formed in the collecting portion 20c for replenishing the developing liquid 4, toner and carrier liquid into the reservoir 11.

10 Drive means, not shown, rotates the developing roller 12 clockwise, as viewed in FIG. 1. The developing roller 12 partly protrudes from the reservoir 11 via an opening formed in the reservoir 11 and contacts the drum 1 to thereby form a nip. The developing roller 12 moves in the same direction as the drum 1, as seen at the nip. The developing liquid 4, forming a thin layer on the developing roller 12, is nipped between the developing roller 12 and the drum 1.

A power source or voltage applying means, not shown, is connected to the developing roller 12 so as to apply a bias for development to the developing roller 12. The bias forms an electric field for development at the nip between the developing roller 12 and the drum 1. The electric field exerts an electrostatic force on the toner contained in the thin liquid layer, which is passing



through the nip in accordance with the rotation of the drum 1. As a result, the toner is transferred from the developing roller 12 to the drum 1, developing the latent image formed on the drum 1. At the same time, the electric field causes the toner not facing the latent image to return to the surface of the developing roller 12. This prevents the toner from depositing on the non-image area of the drum 1 while allowing only a small amount of carrier liquid to deposit on the above area of the drum 1.

10           The collecting blade 12 is positioned in the upper part of the collecting portion 20c. The collecting blade 12 scrapes off the thin liquid layer left on the surface of the developing roller 12 that has moved away from the nip between the developing roller 12 and the drum 1. The developing liquid 4 collected by the blade 12 is returned to the collecting portion 20c.

Configurations unique to the illustrative embodiment will be described with reference to FIG. 2. As shown, the developing roller 12 is made up of a core or shaft 12a formed of metal or similar conductive material and a roller 12b formed of silicone rubber, urethane rubber or similar elastic material. A power source 13 is connected to the core 12a in order to apply the previously mentioned bias to the core 12a. The drum 1 and roller 12b are pressed against each other by a preselected pressure,

forming a nip having a width W.

As for the roller 12b, carbon black or similar conductive substance is dispersed in the elastic material to implement a volume resistivity of  $0 \Omega \cdot \text{cm}$  to  $10^7 \Omega \cdot \text{cm}$ .  
5 When the bias is applied from the power source 13 to the core 12a, the surface potential of the roller 12b becomes substantially equal to the bias. As soon as the surface potential of the roller 12b is stabilized, it stabilizes  
— the strength of the electric field formed between the roller 12b and the drum 1. This successfully obviates  
10 irregular development ascribable to the unstable strength of the electric field. A series of experiments showed that when the volume resistivity of the roller 12 was  $10^8 \Omega \cdot \text{cm}$  or above, the surface potential of the roller 12b was  
15 sometimes lower than the bias for development due to voltage drop. As a result, the strength of the electric field fluctuated in accordance with the rotation of the roller 12b and rendered development irregular.

The roller 12b is produced by, e.g., extrusion  
20 molding and provided with a ten-point mean surface roughness of  $3 \mu\text{m}$  or less. The roller 12b with such a surface roughness causes a minimum of fine irregularity to appear on the surface of the liquid layer carried thereon, thereby reducing irregular development. It was  
25 experimentally found that by so reducing irregular

development, a smooth solid image shown in FIG. 3 was achieved. When the ten-point surface roughness of the roller 12b was 4  $\mu\text{m}$  or above, fine irregularity sometimes appeared on the surface of the thin liquid layer. For  
5 example, when the liquid layer on the roller 12b was 3  $\mu\text{m}$  to 10  $\mu\text{m}$  thick, the surface level of the thin liquid layer sometimes subtly waved due to the influence of the surface configuration of the roller 12b, resulting in fine  
— irregularity and therefore irregular development.

10 Assume that the roller 12b is formed of a foam material in order to exhibit desired elasticity. Then, the cellular structure of the foam material makes the contact pressure (nip pressure hereinafter) between the drum 1 and the roller 12b irregular. The developing liquid  
15 4 forced out of the portions where the nip pressure is high enters the portions where the nip pressure is low, resulting in the irregular thickness of the thin liquid layer. The irregular thickness is also brought about by the fact that the developing liquid 4 enters the portions  
20 where the inside of the cellular structure is exposed, but does not enter the other portions where it is not exposed. Such irregularities in thickness make the distance between the surface of the drum 1 and the elastic roller 12b non-uniform and thereby render the electrostatic force  
25 acting on the toner unstable. More specifically, the

electrostatic force is weaker at portions where the above distance is long than at portions where it is short. FIG. 4 shows a specific solid image rendered rough by the unstable electrostatic force. The roller 12b should  
5 therefore preferably be formed of an elastic material other than foam materials.

The toner does not instantaneously migrate to the roller 12b or the drum 1 at the nip, but needs a certain period of time to do so. This period of time is noticeably  
10 effected by the viscosity of the developing liquid 4. To insure high-quality images, it is necessary to guarantee a sufficient period of time T for the toner to pass through the nip and surely migrate at the nip. The period of time T is expressed as:

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$$T \text{ (sec)} = L \text{ (mm)} / V \text{ (mm/sec)}$$

where W denotes a nip width, and V denotes a process speed, i.e., the linear velocity of the drum 1 and developing  
20 roller 12.

As the above equation indicates, a decrease in the process speed V translates into an increase in the period of time T, but undesirably lowers the printing speed. It is therefore desirable to extend the period of time T by  
25 increasing the nip width W. However, if the nip pressure

is excessively increased to increase the nip width  $W$ , it is likely that the roller 12b permanently deforms. It follows that the hardness of the roller 12b should preferably be  $30^\circ$  or below in JIS-A scale or  $60^\circ$  or below in Asker-C hardness.

FIG. 5 shows a relation between the nip pressure and the hardness of the roller 12b with respect to a given nip width  $W$ . As FIG. 5 indicates, for a given nip width  $W$ , the required nip pressure decreases with a decrease in the JIS-A hardness of the roller 12b. Assume that the acceleration of gravity is  $N$ . Then, if the nip pressure is reduced to  $0.3 \text{ N/m}^2$  or less, its influence on the drum 1, developing roller 12 and drivelines for driving them is presumably negligible in practice, so that the permanent deformation of the roller 12b is suppressed.

FIG. 6 is a graph showing a relation between the nip width  $W$  and the hardness of the roller 12b with respect to a given nip pressure. As shown, for a given nip pressure, the required nip width  $W$  decreases with a decrease in the hardness of the roller 12b. Also, when the hardness of the roller 12b exceeds  $30^\circ$  in JIS-A scale, the rate of variation of the nip width  $W$  sharply decreases. It is to be noted that JIS-A hardness and Asker-C hardness have some degree of correlation;  $30^\circ$  in JIS-A scale substantially corresponds to  $60^\circ$  in Asker-C scale. In practice, it is

extremely difficult to produce an elastic body whose JIS-A hardness is less than 3°. It is therefore desirable to provide the roller 12b with a hardness of 3° to 30° in JIS-A scale or a corresponding hardness in Asker-C scale. Further, it is desirable to uniform the hardness in the axial and circumferential directions of the roller shaft. This is successful to surely uniform the nip pressure and therefore the thickness of the liquid layer.

— The surface of the drum 1 should preferably be formed of a-Si so as to be protected from damage ascribable to contact with the roller 12b and from deterioration ascribable to water absorption and swelling.

In summary, it will be seen that the present invention provides a developing unit and an image forming apparatus using the same having various unprecedented advantages, as enumerated below.

(1) Irregular development ascribable to the unstable strength of an electric field for development is obviated, so that irregular development is reduced.

(2) Irregular development ascribable to fine irregularities on the surface of a developing liquid, which is carried on a roller, is reduced to, in turn, reduce irregular development.

(3) A nip width great enough for a developing substance to surely migrate from the roller to a latent

image formed on an image carrier is guaranteed. This can be done without increasing the diameter of the roller or pressing the roller against the image carrier by a pressure that would cause the roller to permanently deform.

5           (4) The surface of the image carrier is protected from damage ascribable to its contact with a developer carrier and from deterioration ascribable to water absorption and swelling. This extends the service life  
— of the image carrier.

10           Various modifications will become possible for those skilled in the art after receiving the teachings of the present disclosure without departing from the scope thereof.